

Calibration of fibre optic chromatic dispersion test sets

The European Standard EN 61744:2005 has the status of a
British Standard

ICS 33.180.01

National foreword

This British Standard is the official English language version of EN 61744:2005. It is identical with IEC 61744:2005. It supersedes BS EN 61744:2001 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee GEL/86, Fibre optics, which has the responsibility to:

- aid enquirers to understand the text;
- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;
- monitor related international and European developments and promulgate them in the UK.

A list of organizations represented on this committee can be obtained on request to its secretary.

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**Calibration of fibre optic chromatic dispersion test sets
(IEC 61744:2005)**

Etalonnage des ensembles d'essai
de la dispersion chromatique
des fibres optiques
(CEI 61744:2005)

Kalibrierung von Prüfaufbauten
zur Bestimmung der chromatischen
Dispersion
(IEC 61744:2005)

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CENELEC

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Foreword

The text of document 86/236/FDIS, future edition 2 of IEC 61744, prepared by IEC TC 86, Fibre optics, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 61744 on 2005-09-01.

This European Standard supersedes EN 61744:2001.

The principal change is the addition of reference to wavelength in vacuum. This reference is critical for accurate production, measurement and sale of products in the emerging market applications of fibre optics such as dense wavelength division multiplexing (DWDM) systems.

The following dates were fixed:

- latest date by which the EN has to be implemented
at national level by publication of an identical
national standard or by endorsement (dop) 2006-07-01
- latest date by which the national standards conflicting
with the EN have to be withdrawn (dow) 2008-09-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 61744:2005 was approved by CENELEC as a European Standard without any modification.

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0 Introduction

0.1 Chromatic dispersion in optical fibres

Chromatic dispersion is the variation with optical light wavelength of the light propagation delay time in a length of fibre. This variation can cause bandwidth limitation in the fibre when used to transmit communication signals. For a more detailed explanation, refer to Annex C and IEC 60793-1-1.

0.2 Chromatic dispersion (CD) test sets

CD test sets are used to measure the chromatic dispersion properties of optical fibres and typically comprise an optical source of known wavelength(s), a fibre light input coupling and output coupling means, optical detection means, and electronic or optical means of determining the optical delay or dispersion at the source wavelength. There are several variants each requiring slightly different calibration techniques. Refer to Annex C for further details.

In general, all CD test sets produce an output of fibre delay or dispersion versus the light wavelength, typically in graphical form. Thus, wavelength constitutes the 'x-axis' and delay or dispersion the 'y-axis'.

0.3 Overview of calibration procedures described in this standard

The requirement to calibrate the CD test set, traceable to known standards, is essential for quality control in fibre optic production, fibre research and similar activities. This standard describes the detailed procedures used to establish calibration of a CD test set.

Calibration of a CD test set is established by applying known artefacts or standards (themselves calibrated to reference standards) to the CD test set, measuring its response and adjusting (correcting) the CD test set to achieve results that match the standards used. In this way the CD test set results will be brought to close agreement with other CD test sets also calibrated in the manner described in this standard.

Primarily the artefacts or standards used are as follows:

- a) wavelength artefact(s) used to calibrate the light source wavelength(s) used by the CD test set. This is to establish the correct excitation wavelength for the system (the 'x-axis') in order that the correct delay or dispersion (the 'y-axis') be determined subsequently;
- b) delay or dispersion artefact(s) used to calibrate the delay or dispersion response of the CD test set (the 'y-axis').

Calibration can only be carried out using these artefacts. After a calibration has been completed, a calibration period is defined over which the CD test set is deemed to remain calibrated. At the end of this period, it would be necessary to establish if the CD test set calibration requires updating (changing); this can be performed using the artefact described above, or by use of a known standard fibre (reference fibre) whose chromatic dispersion is known. This is referred to as calibration checking. The fibre forms a stable source of known dispersion and may be used as a simple dispersion artefact.

If it is found that the calibration has not changed within the required uncertainty limits, then it is possible to simply extend the calibration period again by a defined amount.

If, however, it is found that the CD test set measurement results have changed significantly compared to the user requirements (i.e. the test set has drifted), then calibration using the artefacts (if not already carried out at this time) should be carried out and the calibration renewed.

The above rationale ensures that the CD test set calibration is only ever performed using known standards (artefacts), but that if the CD test set is sufficiently stable over the calibration period selected, then a simple check of calibration can suffice to ascertain this and to (justify) allow the extension of the calibration period. The extension can be repeated indefinitely over many calibration periods, provided the CD test set continues to remain within uncertainty limits over the entire set of calibration periods.

In order to be considered calibrated and in conformance with this standard, a CD test set must have its calibration adjusted based on comparison to artefacts for the primary parameters of wavelength and delay [dispersion]. In all cases, this calibration of primary parameters is necessary, but may or may not be sufficient, to ensure calibration of the CD test set to the required uncertainty.

In addition, it may be necessary to also confirm or compensate the calibration state of a CD test set using a calibrated reference fibre. The CD test set calibration compensation is explained more fully in Annex D. It should be noted that use of a calibrated reference fibre alone is not sufficient to ensure calibration of a CD test set.

It should also be noted that if a calibrated CD test set undergoes calibration compensation using a calibrated reference fibre, the scope and extent of its calibration is limited to the conditions used at the time of calibration compensation (i.e. wavelength, fibre type, loss regime, etc.) Care should be exercised that test sets calibrated and compensated in this manner are used only within the appropriate limits of their calibration extent. The adjustments required to effect compensation on one set of wavelengths for one fibre type may increase the uncertainty of measurement of other fibre types with different minimum dispersion wavelengths.

In this document, the reference medium for wavelength and the velocity of light is assumed to be in normal air. However, since the velocity of light in air (or rather, the refractive index of air) is dependent on barometric pressure, humidity and temperature, it is sometime advantageous to reference the velocity of light in vacuum, and hence define the refractive index = 1,0000000. This leads to a slight shift in the wavelength scale of the order of 0,3 nm to 0,4 nm depending on the wavelength value, between the so-called “wavelength in air” (as assumed in this document) and the wavelength in vacuum, also called “vacuum wavelength”.

Vacuum wavelength is typically used where very accurate dispersion control is required such as in long-haul or submarine fiber cable systems. CD test sets for measuring fibers used in these applications are typically calibrated to vacuum wavelength, e.g. using a wavemeter, or by mathematical correction of results obtained with an internal air wavelength calibration.

In order that the user be familiar with the conversion from air wavelength and the mathematical corrections involved, an informative annex, Annex E, is provided.

CALIBRATION OF FIBRE OPTIC CHROMATIC DISPERSION TEST SETS

1 Scope

This International Standard provides standard procedures for the calibration of optical fibre chromatic dispersion (CD) test sets. It also provides procedures to perform calibration checking on CD test sets whereby an extension to the test set calibration period may be obtained.

This standard is applicable to all types of CD test sets, with the exception that measurements on multimode optical fibres are excluded.

The purpose of this standard is to define a standard procedure for calibrating optical fibre chromatic dispersion (CD) test sets. The detailed calibration steps used vary according to the measurement technique used in the CD test set.

Whilst it is acknowledged that chromatic dispersion also occurs in multimode fibre and this fibre may be measured on many CD test sets, this standard will restrict discussion to single mode fibre measurements only.

The purpose of the procedures outlined in this standard is to focus manufacturers and users of CD test sets toward the reduction of measurement uncertainty in chromatic dispersion determination in optical fibres under all applicable conditions. The procedures apply to calibration laboratories and to the manufacturers or users of CD test sets for the purpose of

- a) calibrating CD test sets;
- b) setting specifications of CD test sets;
- c) extending the calibration period of an already calibrated CD test set.

Use of the procedures also allows correct evaluation of CD test set uncertainty, relative and traceable to appropriate (for example, national) standards.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-731, *International Electrotechnical Vocabulary (IEV) – Chapter 731: Optical fibre communication*

IEC 60825-1, *Safety of laser products – Part 1: Equipment classification, requirements and user's guide* ¹⁾

¹⁾ A consolidated edition 1.2 exists (1998) that includes IEC 60825-1 (1993) and its Amendment 1 (1997) and Amendment 2 (2001).

IEC 62129, *Calibration of optical spectrum analyzers* ²⁾

ISO 9000 (all parts), Quality management and quality assurance standards

BIPM/IEC/IFCC/ISO/IUPAC/IUPAP/OIML:1995, *Guide to the Expression of Uncertainty in Measurement (GUM)*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

For the purposes of this document, the terms and definitions contained in IEC 60050(731) and the following definitions apply.

3.1

accredited calibration laboratory

calibration laboratory authorized by the appropriate national standards laboratory to issue calibration certificates with a minimum specified uncertainty, which demonstrate traceability to national standards

3.2

adjustment

modifying the hardware or firmware of a CD test set with the intention of making the measurement result of the CD test set equal to that of a national standard or a similar calibrated CD test set. This has the effect of correcting all subsequent measurements on that CD test set

3.3

artefact

device, instrument or equipment used in the process of calibrating a CD test set, for both wavelength and delay [dispersion]. The artefact is a means of transferring calibration of these parameters to a CD test set

3.4

calibration

process by which the relationship between the values indicated by the infant CD test set and known values of the calibration standard is established under specified conditions

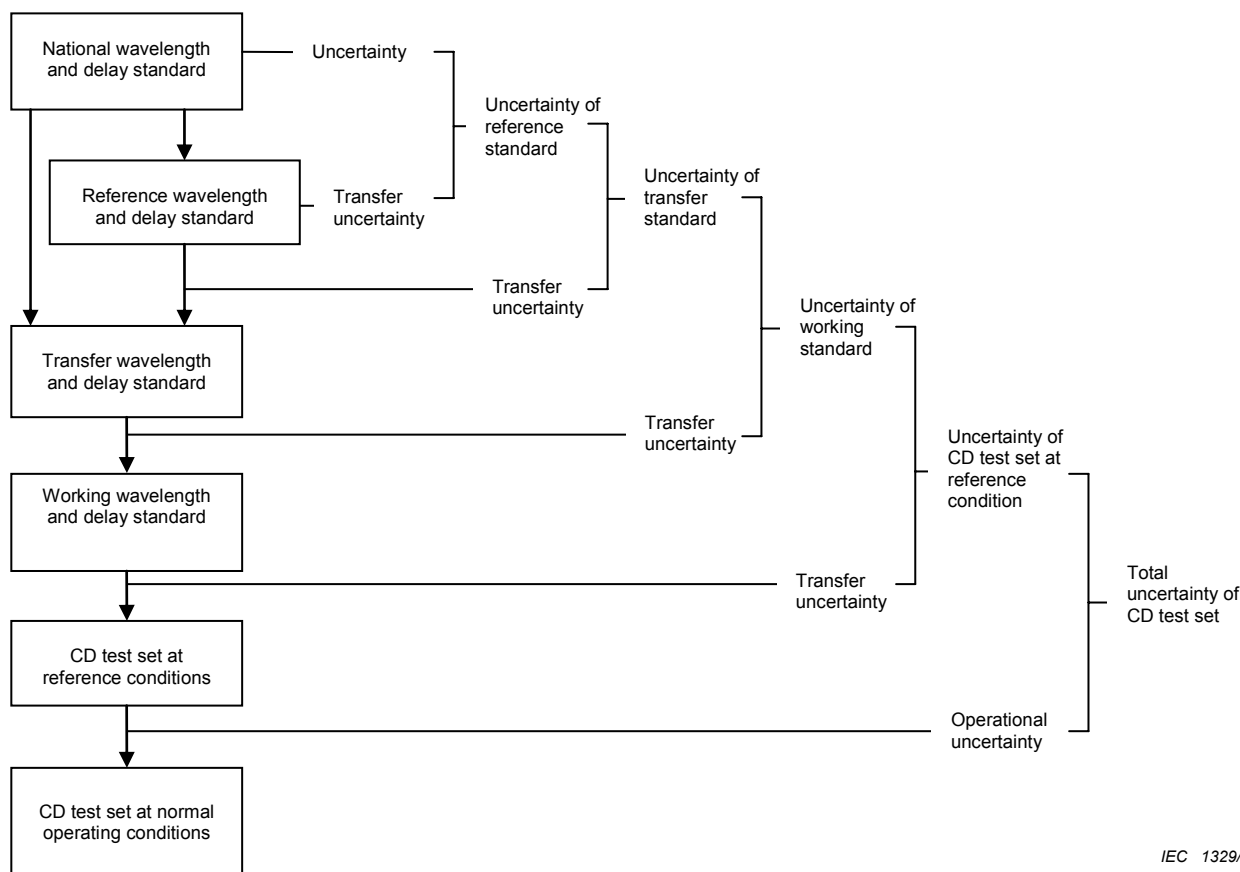
NOTE The intention of calibration is to bring all CD test sets into substantial agreement with a suitable national standards laboratory. This may be performed by first comparing the relevant parameter of a measurement artefact with that produced by the CD test set, followed by transfer of that result, either by adjustment of the CD test set or by documentation of a calibration factor(s) in a calibration certificate. The pertaining environmental conditions and instrument state are usually recorded. Calibration includes estimation of all uncertainties. The use of reference fibres is for calibration checking only.

3.5

calibration chain

unbroken chain of transfers from a primary standard to the CD test set via reference standards, intermediate and/or working standards (see Figure 1)

²⁾ To be published.



IEC 1329/05

Figure 1 – Typical calibration chain for CD test sets

3.6

calibration checking

process of establishing that a CD test set which has been previously calibrated, but is nearing the end of its calibration period, remains within specified uncertainty limits. If the CD test set has drifted outside these limits, then calibration is required. Otherwise, the calibration period can be extended for a stated period, and calibration checking may be repeated indefinitely if the CD test set remains stable over successive calibration periods

NOTE Calibration checking is performed using a reference fibre or working standard. Essentially calibration checking is the first part of the process of calibration, but without the additional process of transfer or adjustment.

3.7

calibration period

interval of confirmation

time period over which a calibration performed in accordance with the procedures in this standard is deemed to remain within the uncertainty limits set. (i.e. remain valid). The time allotted will be governed by individual user requirements, CD test set characteristics, past experience, environmental conditions, etc. and by monitored CD test set measurement result experience in normal use (see also ISO 10012)

3.8**calibration standard**

artefact that is calibrated against a reference standard and is used to calibrate CD test sets. The artefact may be a delay [dispersion] or a wavelength standard artefact. Proper use of the calibration standard ensures traceability. The term includes the national standard, reference standard, the transfer standard and the working standard in descending order of metrological uncertainty

3.9**central wavelength**

power-weighted mean wavelength of a light source in air, in units of nanometers (nm)

For a continuous source spectrum, the central wavelength λ_c in air is defined by the following integral, where the integration limits enclose the entire spectrum of the source:

$$\lambda_c = (1/P_{\text{total}}) \times \left[\int p(\lambda) \times \lambda \, d\lambda \right] \quad (1)$$

where

$P_{\text{total}} = \int p(\lambda) \, d\lambda$ is the total optical source power.

For a spectrum consisting of i discrete lines, the centre wavelength in air λ_c is defined as:

$$\lambda_c = (1/P_{\text{total}}) \times \left[\sum_i p_i \lambda_i \right] \quad (2)$$

where

$p(\lambda)$ is the spectral power density of the source in W/nm;

λ_c is the central wavelength in air in nanometers;

λ_i is the i^{th} discrete line in nm;

p_i is the power levels at λ_i in W;

$P_{\text{total}} = \sum_i p_i$ is the total power in W.

3.10**chromatic dispersion (CD) test sets**

instrument capable of measuring the chromatic dispersion of a single mode fibre at various wavelengths in the transmission windows of interest, typically the 1 310 nm and/or 1 550 nm wavebands

3.11**combined standard uncertainty**

combination of a number of individual standard uncertainties

NOTE The term “accuracy” should be avoided in this context.

All calibration reports and technical data sheets should report the combined standard uncertainty of the CD test set as an overall expanded uncertainty, U , with the applicable confidence level, for example 95,5 % or 99,7 %.

3.12

confidence level

estimation of the probability that the true value of a measured parameter lies in the given range (the expanded uncertainty)

3.13

correction offset, CO

number that is added to or subtracted from the measurement result of a CD test set to correct for a known physical effect or systematic uncertainty

3.14

coverage factor, k

used to calculate the expanded uncertainty, U , from the standard uncertainty σ (see 3.15)

3.15

expanded uncertainty, U

(confidence interval)

range of values within which the measurement parameter, at the stated confidence level, can be expected to lie. It is equal to the coverage factor k times the standard uncertainty σ :

$$U = k \times \sigma \quad (3)$$

NOTE When the distribution of uncertainties is assumed to be normal and a large number of measurements are made, then confidence levels of 68,3 %, 95,5 % and 99,7 % correspond to values of k of 1, 2 and 3, respectively.

The measurement uncertainty of a CD test set should be specified in the form of expanded uncertainty U .

3.16

infant reference fibre

fibre whose dispersion is measured against a parent reference fibre. The infant reference fibre would then be intended for calibration checking of a CD test set

3.17

instrument state

complete description of the measurement conditions and state of the CD test set during the calibration process

NOTE Typical parameters of the instrument state are the wavelength range in use, the data fit model (as applicable), warm-up time and other instrument settings.

3.18

measurement result

displayed or electrical output of any CD test set, in dispersion D in units of

- $\text{ps} \times \text{nm}^{-1} \times \text{km}^{-1}$, lambda zero λ_0 in units of nm, or zero dispersion slope S_0 in units of
- $\text{ps} \times \text{nm}^{-2} \times \text{km}^{-1}$, after completing all actions suggested by the operating instructions, for example warm-up.

3.19**national standard**

standard whose measurement is traceable to fundamental properties, such as the speed of light, which is recognized by an official national decision and used as the basis for fixing the value, in a country, of all other standards of the quantity concerned

3.20**national standards laboratory**

body or laboratory that maintains and operates the national standard

3.21**operating range**

all conditions of, for example, the dispersion, temperature and other influencing quantities, over which the CD test set is designed to perform within the stated expanded uncertainty

3.22**parent reference fibre**

reference fibre which is used as the reference for generating an infant reference fibre. The parent reference fibre may be used for calibration checking of a CD test set

3.23**reference standard**

artefact calibrated against a national standard and used to calibrate CD test sets. The artefact may be a delay [dispersion] or wavelength standard artefact. Proper use of the calibration standard ensures traceability. The term includes the national standard, reference standard, the transfer standard and the working standard in descending order of metrological uncertainty

NOTE In this standard, reference standard can also be taken to mean the fibre (infant or parent) which is used as the reference for calibration checking of a CD test set.

3.24**scaling factor,****SF**

ratio of known standard values for a standard artefact to the values indicated by the CD test set when no correction offsets are applied. The factors can apply to wavelength, delay [dispersion] calibration, as well as to recorded zero dispersion wavelength, slope and actual dispersion data values when using a calibrated reference fibre (see Annex D).

3.25**spectral bandwidth**

full-width half-maximum (FWHM) spectral width of the source

If the source exhibits a continuous spectrum, then the spectral bandwidth, B , shall be the full-width-half-maximum (FWHM) of the spectrum.

If the source exhibits a spectrum consisting of i discrete line (for example, a laser diode with a multiple-longitudinal mode spectrum), then the FWHM spectral bandwidth B shall be the r.m.s. spectral bandwidth, multiplied by 2,35 (assuming the source has a Gaussian envelope):

$$B = 2,35 \times \left[\left(\frac{1}{P_{\text{total}}} \right) \times \left(\sum_i p_i \lambda_i^2 \right) - \lambda_c^2 \right]^{1/2} \quad (4)$$

where

λ_c is the central wavelength (see 3.9) of the laser diode, in nm;

$P_{\text{total}} = \sum_i p_i$ is the total power, in W;

p_i is the power of i^{th} longitudinal mode, in W;

λ_i is the wavelength of i^{th} longitudinal mode, in nm.

3.26

standard uncertainty

standard deviation

uncertainty of a measurement result expressed as a standard deviation σ

NOTE 1 For further information, refer to Annex A, and the *Guide to the Expression of Uncertainty in Measurement*.

NOTE 2 In order to combine standard uncertainties from different sources (see Annex A) it is important that they are all stated at the same confidence level, i.e. for normally distributed data, at a confidence level of 68,3 %. This may be achieved by the use of each respective coverage factor k which is determined with reference to student's t -distribution for each individual uncertainty component.

3.27

traceability

ability to demonstrate, for a measurement result or a CD test set, an unbroken calibration chain originating from a national standard

CD test sets calibrated by the procedures of this standard are traceable. In the sense of this standard, direct traceability of the measurement result to either a national standards laboratory or to an accredited calibration laboratory is demonstrated. Such traceability includes the calibration schedules of all artefacts in the calibration chain and detailed calculations of all (cumulative) transfer uncertainties in the calibration chain. The use of a reference fibre or working standard alone to compare/monitor CD test set calibration will not establish or re-establish traceability, but only extend the duration of the traceability certification (calibration period) if no change is found.

3.28

transfer

part of the calibration process where, following comparison of the relevant parameter of a calibrated artefact to that of a CD test set, the artefact result is applied to the CD test set

Transfer may be performed either by adjustment of the CD test set, or by documentation of a calibration factor in a calibration certificate.

3.29

transfer standard

intermediary artefact, for example a delay [dispersion] or wavelength artefact used to calibrate new working standards of a corresponding type

3.30

transfer uncertainty

estimate, characterizing the additional uncertainty of a CD test set caused by uncertainties in the calibration process, at the given confidence level

NOTE These uncertainties may arise from the calibration standards or artefacts as well as from the CD test set.

3.31**uncertainty type A**

type A uncertainty is obtained by statistical analysis of a series of observations, such as when evaluating certain random effects of measurement

(see *Guide to the Expression of Uncertainty in Measurement*)

3.32**uncertainty type B**

type B uncertainty is obtained by means other than a statistical analysis of a series of observations, for example an estimation of probable sources of uncertainty, such as when evaluating systematic effects of measurement

(see *Guide to the Expression of Uncertainty in Measurement*)

NOTE Other means may include previous measurement data, experience with or general knowledge of the behavior and properties of relevant materials, artefacts and instruments, manufacturer's specifications, data provided in calibration and other certificates, and uncertainties assigned to reference data taken from handbooks.

3.33**uncertainty limits**

limits of permissible error (of a measuring instrument)

bounds or extreme values of expanded uncertainty permitted by user requirements, manufacturer's specification, regulatory documentation, etc.

(see ISO 10012)

3.34**working standard**

standard which, usually calibrated against a reference standard or transfer standard, is used on a routine basis to check CD test sets

4 Calibration

This clause summarizes the action of calibrating a chromatic dispersion (CD) test set and details the recommendations for the environmental requirements of the calibration facility.

4.1 Rationale for calibration of CD test sets**4.1.1 (Full) calibration**

There are two fundamental and common aspects of the various chromatic dispersion measurement techniques (refer to Annex C):

- a) the use of a series of known (i.e. fixed) or programmable (i.e. variable) source test wavelengths, injected into the test fibre(s);
- b) the electronic or optical measurement of the pulse delay, phase shift, differential phase shift or interference fringe peak position (according to CD test set type) produced by the test fibre(s). Fibre dispersion is obtained by appropriate calculations on the measured data.

In essence, all CD test sets operate with wavelength as a programmed (independent) variable, usually the ordinate (x-axis) and dispersion or time delay as the abscissa (y-axis) as a measured (dependent) variable. By their nature, fibre chromatic dispersion measurements require multiple wavelengths to be programmed. Even in the case of a single dispersion point obtained using the differential phase shift method, two separate wavelength values are used. It is also typical to expect a wide range of dispersion values over a range of wavelengths to be

measured. This makes it impossible merely to transfer calibration from one CD test set to another by exposing them to a single appropriate dispersion source, unless the use of the CD test set is to be restricted in the range of fibre dispersion values measured (see introduction). Rather, it is necessary to independently calibrate wavelength and delay [dispersion] response to establish the minimum possible uncertainty in each.

The process of CD test set calibration shall therefore be broken down into two parts:

- a) ensuring that the programmed wavelengths are calibrated;
- b) exposing the CD test set, to known delays [dispersions] in order to calibrate the delay [dispersion] response.

These two separate calibration stages are generally independent but ideally should always be carried out as unified sequential operations. The detailed procedure is given in 4.3.

In each case, calibration is achieved by exposing the test set to independent transfer standards or artefacts of wavelength and delay [dispersion]. These standards form the calibration chain (Figure 1).

4.1.2 Calibration checking

The rationale of 4.1.1 describes (full) calibration. However, typical routine operational calibration verification (such as may frequently be carried out on CD test sets in use) may be sufficient to perform calibration checking of CD test sets using a reference fibre as a working standard.

The distinction between calibration checking and calibration (i.e. adjustment of correction offsets, etc.) shall be clearly made. While it is sufficient to establish stability of the CD test set using the reference fibre, this is not a substitute for actual calibration (see introduction). The use of this fibre is described in Clause 7.

It is not possible to use the reference fibre for full calibration for the following reasons:

- a) To correctly evaluate the full wavelength range and fibre length range of the CD test set, several reference fibres with differing dispersions would be needed. This is expensive, complex and will introduce a multiplicity of transfer and calibration uncertainty values.
- b) The effect of the data fit and wavelength range used on the reference fibre zero dispersion wavelength, λ_0 , slope, S_0 , and dispersion values means that comparison of systems shall be made only within the wavelength range used.
- c) The " λ_0 -slope" representation, while perfectly adequate for a fibre, cannot cover the possibility that a given CD test set exhibits non-linear delay [dispersion] or wavelength behaviour – a more complete test of the delay [dispersion] and wavelength responses of the CD set is required.
- d) Comparison of CD test sets using a reference fibre requires a standard length value for that fibre to be used in the measurements. Any physical reduction in the length of the fibre (for example, by re-cleaving) shall be kept track of and accounted for and represents a source of potential uncertainty.

Use of a reference fibre allows calibration traceability to national standards to be extended, if it can be satisfactorily established that the instrument and existing correction offsets and scaling factors, etc. are sufficient to provide dispersion results within the applicable uncertainty limits without alteration. This simply means that the CD test set has remained stable since the last actual calibration. Indeed, it is permissible to extend the calibration period indefinitely until such time that the calibration checking indicates that the CD test set has drifted outside these uncertainty limits. At this point, full re-calibration would be required.

It is anticipated that the reference fibre be used also for comparison, as distinct from calibration, between CD test sets under identical (for example, controlled or reference) conditions, test wavelengths, fibre type, fibre length ranges, etc. (see Introduction).

4.2 Preparation for calibration

4.2.1 General advice and organization

The following recommendations apply:

Calibrations should be carried out where possible with facilities (refer to ISO/IEC 17025) that are independent of the other functions of the laboratory/ organization. This independence should include measurement equipment.

The environmental conditions shall be commensurate with the degree of uncertainty that is required for calibration:

- a) the environment shall be clean;
- b) temperature monitoring and control are required;
- c) humidity monitoring and control are required;
- d) all laser sources shall be safely operated (see IEC 60825-1).

All standards used in the calibration process shall be calibrated according to a documented programme with traceability to national standards laboratories or to accredited standards (see Figure 1). It is advisable to maintain more than one standard on each hierarchical level of the calibration chain so that the performance of standards can be verified by comparisons on the same level.

There shall be a documented measurement procedure for each type of calibration performed, giving step-by-step operating instructions and equipment to be used. There should be pro-forma result sheets, uncertainty budgets and calibration certificates.

The calibration laboratory should operate a quality system appropriate to the range of measurements it performs (for example, ISO 9000). There should be an independent scrutiny of measurement results, intermediary calculations and preparation of calibration certificates.

4.2.2 Test environmental requirements

The following requirements shall be observed:

- a) all tests shall be performed at an ambient temperature of $23\text{ °C} \pm 3\text{ °C}$ with a relative humidity of $(50 \pm 20)\%$ unless otherwise specified;
- b) the CD test set, test apparatus and equipment shall be given sufficient time to reach thermal equilibrium with the environment in accordance with the manufacturer's recommendations for each item of equipment, before commencement of any part of the calibration procedure;